Journal of Evrimata: Engineering and Physics
Vol. 02, No. 02, December, 2024, p.118 – 124 e-ISSN: 3025-1265

An Implementation of Early Warning System for Air Condition Using IoT and Instant Messaging

Alfiandi Aulia Rahmadani[1], Budhy Setiawan[1], Yan Watequlis Syaifudin[2]✉, Nobuo Funabiki[3], Triana Fatmawati[2], Indrazno Siradjuddin[1]

[1]*Dept. of Electrical Engineering, State Polytechnic of Malang, Malang, Indonesia*
[2] *Dept. of Information Technology, State Polytechnic of Malang, Malang, Indonesia*
[3]*Dept. of Elec. and Comm. Engineering, Okayama University, Okayama, Japan*

1941170055@student.polinema.ac.id, budhy.setiawan@polinema.ac.id, qulis@polinema.ac.id, funabiki@okayama-u.ac.jp, triana@polinema.ac.id, indrazno@polinema.ac.id

Article Information

Manuscript Received 2024-12-05
Manuscript Revised 2024-12-29
Manuscript Accepted 2024-12-29
Manuscript Online 2024-12-31

ABSTRACT

Air pollution poses a significant threat to human health and environmental sustainability, exacerbated by anthropogenic activities such as industrial emissions, vehicle exhaust, and fossil fuel combustion. Major pollutants include carbon monoxide (CO), nitrogen dioxide (NO_2), hydrocarbons (HC), sulfur dioxide (SO_2), ozone (O_3), particulate matter ($PM_{2.5}$), particulate matter (PM_{10}), and etc. In this study, an Early Warning System (EWS) was developed integrating sensors, microcontroller, IEEE 802.11 network, web interface monitoring, and Instant Messaging. The system uses the CART algorithm to analyze the data, with sensors that detect CO, NO_2, and HC. The evaluation of the system demonstrated its effectiveness, with recorded pollutant concentrations of 1.401 ppm for CO, 0.639 ppm for NO_2, and 0.860 ppm for HC, and identified correlations between these pollutants. The EWS proved capable of providing timely alerts, ensuring continuous monitoring and management of indoor air quality, and contributing to public health and environmental protection.

Keywords: EWS, air pollutants, IoT, air quality, instant messaging

1. INTRODUCTION

Air is a vital element in our lives today. This element is starting to be threatened by increasingly worrying pollution. These pollutants include several levels, namely SO_2, O_3, $PM_{2.5}$, PM_{10}, CO, NO_2, HC, Dust (TSP), PB, Fluorine Index, Chlorine and Sulphate Index [1], [2]. Over the years, the rapid increase in the use of motor vehicles and industrial activities along with population growth has caused serious problems for air quality and human health [3], [4], [5], [6]. At certain levels, it can have a dangerous impact on human health, such as respiratory diseases, strokes, lung cancer, and even death [7], [8], [9], [10].

CO is produced by incomplete combustion [11], [12], [13]. CO is a dangerous gas that causes respiratory and cardiovascular problems. NO_2 from the combustion process affects lung health and can worsen asthma. HC formed during the combustion of fossil fuels, are carcinogenic and mutagenic. These pollutants are chemically related in that CO is formed from incomplete combustion, while NO_2 is produced from nitrogen reacting with oxygen at high temperatures, and HC emissions occur when combustion is incomplete [14], [15], [16]. Air quality is assessed using ISPU scores, categorizing pollutants into levels from subtle to hazardous, guiding health standards to reduce the impact of pollution.

This study presents the proposal of an EWS for air pollutants such as CO, NO_2, and HC that integrates sensors, a microcontroller, a back-end server, a web interface, and a Telegram bot, also applies the CART algorithm for data analysis. Strategically placed sensors in the laboratory collect data that are sent to a microcontroller for initial processing and then transmitted to a central server for analysis and storage. The web interface displays real-time data, while the Telegram bot sends immediate notifications when pollutant levels change significantly. The web application offers features such as real-time data display, CSV data downloads, and integration with Telegram for alerts.

The evaluation of the air quality EWS demonstrated its effectiveness in monitoring pollutants such as CO, NO_2, and HC, using the *Air Pollution Standards Index* (ISPU) to categorize air quality and issue alerts when necessary. During tests conducted in November and December 2023, the system successfully recorded air quality data, identifying a rare hazardous event and frequent moderate-quality readings. The results showed average pollutant concentrations of 1.401 ppm for CO, 0.639 ppm for NO_2, and 0.860 ppm for HC, with small fluctuations and stable readings. The early warning notifications, sent through Telegram, effectively alerted users to changes in air quality, mainly when it fell into medium or dangerous categories.

The structure of the rest paper consists of Section II presents several studies related to this paper, Section III describes the measurement of air conditions, Section IV describes the design of the early warning system, Section V describes the implementation of the system, Section VI evaluates the implemented system, and finally, Section VII presents a comprehensive conclusion with future work.

2. RESEARCH SIGNIFICANCE

This research addresses the urgent issue of air pollution and its detrimental effects on public health and environmental sustainability by developing an Early Warning System (EWS) for indoor air quality monitoring. By leveraging advanced technologies such as sensors, microcontrollers, IEEE 802.11 networks, and web-based interfaces, this study provides a practical and innovative approach to managing pollutant levels in real-time. The use of the CART algorithm enhances the system's ability to analyze and identify correlations among pollutants like carbon monoxide (CO), nitrogen dioxide (NO_2), and hydrocarbons (HC), enabling data-driven decision-making. The findings not only demonstrate the system's effectiveness in detecting and monitoring air quality but also highlight its potential as a preventive tool to mitigate health risks and environmental impacts.

This research is significant for advancing IoT-based environmental monitoring systems and offers scalable solutions that can be adapted to other settings. The integration of real-time alerts through instant messaging further underscores the practicality of the system in promoting immediate action to safeguard public health. Ultimately, this study contributes to the broader goals of sustainable development and environmental protection while serving as a model for similar efforts worldwide.

3. RELATED STUDIES

In 2019, Salman et. al. conducted a study on the development and implementation of a wireless sensor network (WSN) based indoor air quality monitoring system for real-time data visualization and recording, using infrared sensors that measure CO_2, temperature, and humidity. This study required high costs when applied in large buildings, and the spatial and temporal prediction capabilities of this system were limited [17].

In 2020, Dionova et al. conducted a study that developed a Fuzzy Inference (FIS) based system to monitor and control indoor air quality and thermal comfort. This system is able to measure and classify air quality but is limited to the pollution parameters used. In this study, the reasoning process is inadequate to accurately classify air pollutants and thermal comfort separately [18].

In 2020, Sharma et al. conducted a study on the ICEEMDAN-OS-ELM system. This system is useful in processing complex data to predict pollutants such as $PM_{2.5}$ and PM_{10} with real-time data visibility through a hybrid machine learning model [19]. The strength of the system lies in its ability to handle large-scale data and provide detailed predictions for health risk mitigation. However, the system does not focus on ease of use and accessibility to users, making it unsuitable for practical daily applications.

In 2023, Son et. al. study developed an automated intervention to control indoor air quality (IAQ) based on $PM_{2.5}$ sensors during cooking and cleaning activities. Although the intervention significantly reduced $PM_{2.5}$ concentrations, this difference was not perceived by participants, indicating that the reduction was not sufficient to improve IAQ satisfaction. The study concluded that there was a lack of impact on participant's perceptions, highlighting the need for further research to understand the threshold of perception and the effects of automated control on IAQ [20].

4. AIR CONDITION MEASUREMENTS

This section explains the process of measuring air conditions, including the sources of pollutant gas formation, the chemical reactions of each gas, and the relationship of each level involving the monitoring of the main pollutants such as CO, NO_2, and HC.

Pollutant Substances

Pollutants are substances or materials that cause pollution. When these substances are released into the environment in excessive amounts, they can disrupt the balance of the ecosystem and harm human health. Pollutants can be categorized in various ways, including by source, type, and impact. Some of the main types of pollutants include air pollutants, water pollutants, and land pollutants. In air pollutants, there are several levels of gases that fall into the category of air pollutants, namely, SO_2, O_3, $PM_{2.5}$, PM_{10}, CO, NO_2, HC, Dust (TSP), PB, Fluorine Index, Chlorine and Sulphate Index [1], [2].

A. CO

According to Chiew (2014) [21], carbon monoxide CO is a toxic gas that is tasteless, colorless, and odorless, rendering it invisible to human senses. It is generated by vehicle exhaust as well as incomplete combustion of fuels like wood, coal, and industrial activities [22]. Prolonged exposure to elevated carbon monoxide levels may swiftly result in significant physical harm via many pathways [23]. More severe poisoning may show up as loss of consciousness, sudden cardiac arrest, and death [24]. Mild CO poisoning often manifests with nonspecific symptoms including nausea, headache, and weariness [25], [26].

B. NO_2

Poisonous gas NO_2 is often engaged in a variety of chemical reactions in both the environment and industrial operations [27]. Fossil fuel burning in automobile engines, power plants, industries, lightning strikes, and microbiological activities all produce NO_2. Monitoring and lowering NO_2 levels in the environment is vital because of its detrimental effects on lung health, exacerbation of asthma symptoms, and potential link to cardiac issues [28], [29], [30]. Reliable detection is crucial since prolonged exposure, even at low doses, may result in asphyxiation.

C. HC

HC are organic compounds formed by chemical compounds consisting of two main elements, namely carbon (C) and hydrogen (H). These compounds are formed through the combustion of fossil fuels, industrial processes, the use of organic solvents, emissions from plants (VOC), forest fires, and the activity of microorganisms [31]. HC have been studied intensively because of their carcinogenic, mutagenic, and teratogenic potential [32].

Air Quality

Air is one of the things that every living creature on earth needs. As time goes by, air quality is decreasing due to the large number of human activities. The results of this combustion produce a lot of pollutants. CO tends to be odorless, intangible to the naked eye, and tasteless. In Table 1 is a range of ISPU values where ISPU regulates healthy air standards that meet the level categories determined by the government [1], [2]. In Table 2 several categories of pollutants based on ISPU are presented.

Table 1. ISPU categories and range numbers

No	Category	Number Range
1	Good	000-050
2	Medium	051-100
3	Unhealthy	101-200
4	Very Unhealthy	201-300
5	Dangerous	≥301

Table 2. ISPU values for different pollutants

Number Range	PM_{10}	$PM_{2.5}$	SO_2	CO	O_3	NO_2	HC
000-050	50	15,5	52	4000	120	80	45
051-100	150	55,4	180	8000	235	200	100
101-200	350	150,4	400	15000	400	1130	215
201-300	420	250,4	800	30000	800	2260	432
≥ 301	500	500	1200	45000	1000	3000	648

Pollutants such as CO, NO_2, and HC are especially hazardous due to their invisible and odorless nature, making them difficult to detect without proper monitoring tools. The ISPU values, as shown in Table 1 and Table 2, serve as a benchmark for determining air quality levels. By understanding these pollutant categories and their thresholds, it becomes crucial to develop reliable monitoring systems that can provide real-time data and ensure adherence to air quality standards, ultimately protecting public health and fostering a healthier environment.

5. DESIGN OF EARLY WARNING SYSTEM

This section explains the design of an EWS that includes system requirements and system architecture.

5.1 System Requirements

An EWS is a system designed to detect, analyze, and inform the public about potential dangers or upcoming threats. It integrates CO, NO_2, and HC sensors, a microcontroller, a backend server, a web interface, and a Telegram bot. Sensors are strategically placed in mechatronics laboratories. Data from the sensors is sent to the microcontroller for initial processing, then sent in real-time to the backend server. The backend server stores and analyzes the data, which is then displayed in a web interface for visualization. The instant messaging (Telegram) bot provides real-time notifications when there are significant changes in air quality. This system ensures efficient and timely collection, analysis, and delivery of air pollutant data.

As shown in Figure 1 the system block diagram of EWS air pollution. This system consists of several sensors that detect CO, NO_2, and HC which are all connected to the Nodemcu microcontroller. Data from these sensors is sent wirelessly using a microcontroller and connected to the IEEE 802.11 network to the gateway. The gateway then forwards the data over the internet to the server for data acquisition. Data collected on the server is stored in a database and can be accessed via the web for further analysis. This system also has warning and analytical features to process and display information regarding air pollution levels.

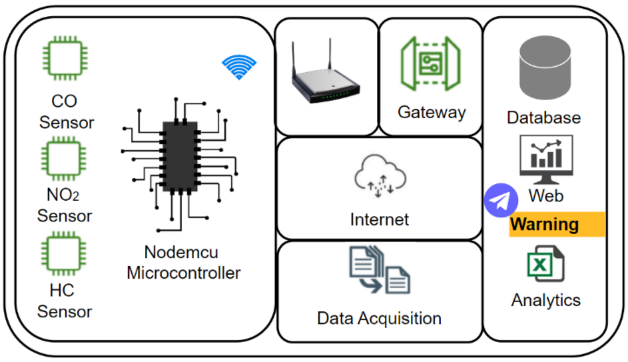

Fig 1. System Block Diagram.

By utilizing a web interface, users can access detailed visualizations, historical data trends, and insights to identify patterns and potential risks. The Telegram bot enhances the system's accessibility by delivering instant alerts directly to users' devices, enabling swift action to mitigate health and safety hazards.

5.2 Design of System Architecture

The system architecture consists of several sensors that detect CO, NO_2, and HC, all of which are connected to a Nodemcu microcontroller. Data from this sensor is sent wirelessly using the IEEE 802.11 network to a gateway. The gateway then forwards the data via the internet to the server for data acquisition. Data collected on the server is stored in a database and can be accessed via the web for further analysis. This system also has warning and analytical features to process and display information regarding air pollution levels.

A. Adopted IoT

The Internet of Things (IoT) in air quality monitoring systems facilitates data sharing and communication between several sensors and devices over an internet network. Pollutant concentrations such as carbon monoxide CO, NO_2, and HC are measured by these sensors, which then transmit the data in real-time to a central server. Continuous, automatic, and real-time monitoring of air quality is made possible by IoT, and this is essential for issuing early warnings and implementing preventative measures. Additionally, by using IoT, the system may make choices based on data and perform data analysis in a dispersed way, increasing operational efficiency.

B. Instant Messaging

The design of this instant messaging system in Figure 2 communication flow in the EWS prototype involves several components via the cloud. Sensors read data which is then collected and processed by a server or computer in the network. This processed data is sent to the cloud, which acts as an intermediary to transmit information to the Telegram bot. The Telegram bot, which interacts with the Telegram server, is used to send notifications or information to users in real-time. This data flow allows the system to provide warnings or information to users via the Telegram platform quickly and efficiently.

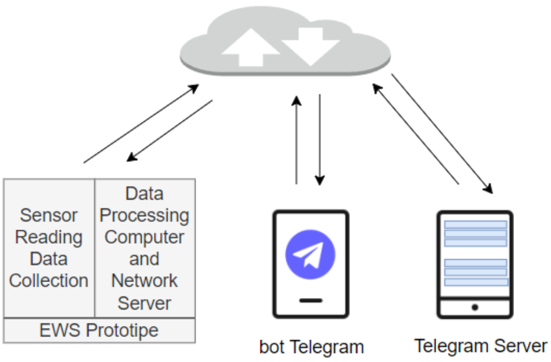

Fig 2. Integration of system architecture

This system adopts an architecture with the main components including IoT sensors, gateways, backend servers, and instant messaging platforms. Air quality data collected by the sensors will be sent to the gateway, and then forwarded to the backend server for processing. The backend server will compare the data value with a predetermined threshold. If the value exceeds the threshold, the server will send a request to the instant messaging platform to send notifications to relevant users.

C. Web Application

The web application features include reading data display, data download feature to CSV format, and integration with Telegram for alert notifications. The website provides a user-friendly interface to display real-time air quality reading data, including CO, NO_2, and HC, and ISPU levels detected by installed sensors. Users can view table data that shows fluctuations in pollutant levels over time, making it easier to monitor air quality conditions at the observation location. This feature allows users to download all the reading data that has been collected in the form of a CSV file, which can then be processed using data analysis software.

6. SYSTEM IMPLEMENTATION

This section discusses implementing the system that includes.

6.1 IoT Functions

The air quality early warning system developed in this research integrates catalytic gas sensors to detect concentrations of CO, NO_2, and HC. The entire system is shown in Figure 3.

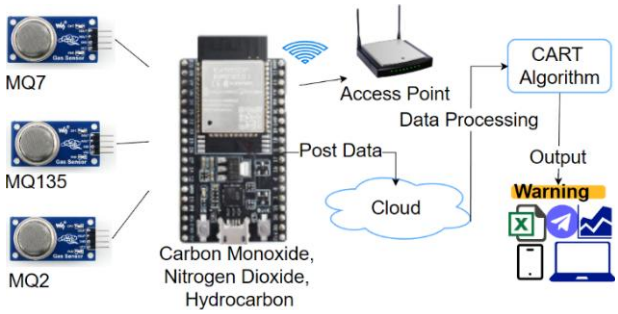

Fig 3. Circuit diagram and working of the EWS.

This system uses the Classification and Regression Tree (CART) algorithm for data analysis and is equipped with a microcontroller for real-time data transmission with the IEEE 802.11 network. Data from the sensors is sent wirelessly to the gateway, which then forwards it to the server for data acquisition and processing. The collected data is stored in a database and can be accessed via a web interface for further analysis.

6.2 Web Interface

The web interface design focuses on ease of use and accessibility, ensuring that users can quickly understand the information presented and take the necessary actions. The website is designed to represent data as in Table 3 then, the reading data can be downloaded into CSV format, besides that it can also be accessed to Telegram via the website.

Table 3. Display of data retrieval results on the web application.

No	Sensor (CO)	Sensor (NO_2)	Sensor (HC)	Location	NO_2	CO	HC	ISPU	Time
1	MQ7	MQ135	MQ2	Indoor	0.61	1.44	0.88	GOOD	12/07/2024 13:02
2	MQ7	MQ135	MQ2	Indoor	0.62	1.44	0.86	GOOD	12/07/2024 13:02
3	MQ7	MQ135	MQ2	Indoor	0.63	1.42	0.88	GOOD	12/07/2024 13:02
4	MQ7	MQ135	MQ2	Indoor	0.63	1.42	0.83	GOOD	12/07/2024 13:02
5	MQ7	MQ135	MQ2	Indoor	0.65	1.45	0.88	GOOD	12/07/2024 13:01
6	MQ7	MQ135	MQ2	Indoor	0.64	1.37	0.84	GOOD	12/07/2024 13:01
7	MQ7	MQ135	MQ2	Indoor	0.61	1.41	0.83	GOOD	12/07/2024 13:01
8	MQ7	MQ135	MQ2	Indoor	0.65	1.42	0.88	GOOD	12/07/2024 13:01
9	MQ7	MQ135	MQ2	Indoor	0.61	1.47	0.88	GOOD	12/07/2024 13:01
10	MQ7	MQ135	MQ2	Indoor	0.62	1.41	0.86	GOOD	12/07/2024 13:01

6.3 Telegram Notifications

Telegram bots are configured to receive data from backend servers and send real-time notifications to users. This configuration involves creating a bot, obtaining an API token, and setting up a webhook to receive data. Telegram bots allow users to receive alerts directly on their devices and respond quickly to dangerous air pollution conditions.

In addition, special bots can be developed for the EWS which automatically sends warnings and information regarding the danger being faced in the form of consecutive messages at certain ISPU levels and statuses.

7. EVALUATION

This section discusses the evaluation of the system.

7.1 Evaluation Scenario

To determine how well the air quality EWS informs users of changes in air quality that might have an impact on their health and safety, a scenario assessment of the system was carried out. The system is intended to monitor important pollutants, such as CO, NO_2, and HC, and classify air quality using the ISPU. When the ISPU classifies air quality as moderate to dangerous, an alarm is sent off. The device reported generally excellent air quality throughout the tests.

7.2 Results on Pollutant Detection

Based on the reading data for CO, NO_2, and HC, the frequency of data collection per minute is 15 data with a delay per data transmission of around 4 seconds. The average CO concentration was recorded at 1,401 ppm with a concentration range of 1,260 ppm to 1,580 ppm, showing small but stable fluctuations. The average NO_2 concentration was 0.639 ppm ranging from 0.580 ppm to 0.700 ppm, showing stability with a slight decrease at some time points. Meanwhile, the average HC concentration was 0.860 ppm with a range of 0.780 ppm to 0.920 ppm, showing small but stable fluctuations. The line graphs for the three gases indicate variations that may be related to changes in activity or environmental conditions at certain times within the data collection period.

7.3 Early Warning Notifications

The early warning system using the Telegram platform is activated if the ISPU category from data processing shows the category "Medium" to "Dangerous". If the ISPU data shows the category "Medium," then a message will be sent automatically by the EWS bot to the user's account via the EWS group. In testing conducted on November 25, 2023, the data showed that the frequency most often appeared in the "Good" category, with only one occurrence of the "Dangerous" category recorded at 22:25:21. Additionally, the data revealed that the frequency most often occurred in the "Medium" category on December 7, 2023, between 14:21:14 and 15:47:21, with a frequency of 8 times per minute. Furthermore, throughout that time range, the "Good" category also often emerges. Based on the test findings, it can be said that Telegram's early warning system can identify changes in the quality of the air and promptly alert users when the air quality falls between "Medium" and "Dangerous".

7.4 Pollutants Interrelationships Analysis

CO concentration in parts per million (ppm) over time in the room is depicted in the graph shown in Figure 4. It can be observed that the CO concentration varies with significant fluctuations. At the beginning of the observed period, the CO concentration was around 1.35 ppm. As time progresses, there is a gradual increase in CO concentration with some obvious spikes. CO concentrations peaked at around 1.55 ppm, before experiencing a fairly sharp decline towards the end of the observation period. The fluctuations seen in the graph indicate that there are dynamic changes in indoor CO levels over the observed period. Sudden spikes and drops can be caused by several factors, such as human activity, room ventilation, or other sources of CO in the room. Overall, analysis of these graphs shows that despite variations in CO concentrations, levels remained within a relatively safe range for this observation period. However, it remains important to monitor continuously to ensure that CO concentrations do not reach dangerous levels.

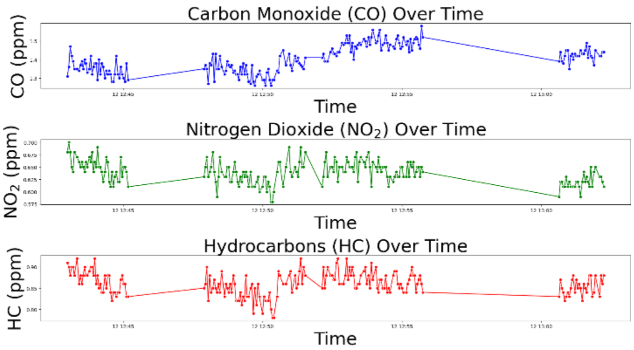

Fig 4. Graph of CO, NO_2, and HC

This graph depicts variations in NO_2 concentration in parts per million (ppm) over time indoors. From this graph, it can be seen that the NO_2 concentration experienced quite significant fluctuations during the observation period. At the beginning of the observation period, the NO_2 concentration was around 0.68 ppm. This concentration then shows a gradual decreasing trend with several significant peaks and valleys. The highest peak seen was around 0.72 ppm, while the lowest concentration recorded was around 0.58 ppm. This graph also shows the presence of some sudden fluctuations that can be caused by changes in indoor activity, such as the use of equipment that produces NO_2 or changes in ventilation. Overall, these graphs show that indoor NO_2 concentrations varied over the observed period. Despite fluctuations, NO_2 concentrations tend to fall within a less dangerous range, but it is still important to continuously monitor NO_2 levels to ensure safe and healthy indoor air quality. The fluctuations that occur also highlight the importance of managing ventilation and sources of NO_2 indoors to avoid increasing concentrations that could be dangerous.

A histogram and boxplot for three gases CO, NO_2, and HC are shown in Figure 5. The boxplot shows possible outliers together with a five-figure statistical overview (minimum, first quartile, median, third quartile, and maximum) and the frequency distribution of the concentration values of each gas.

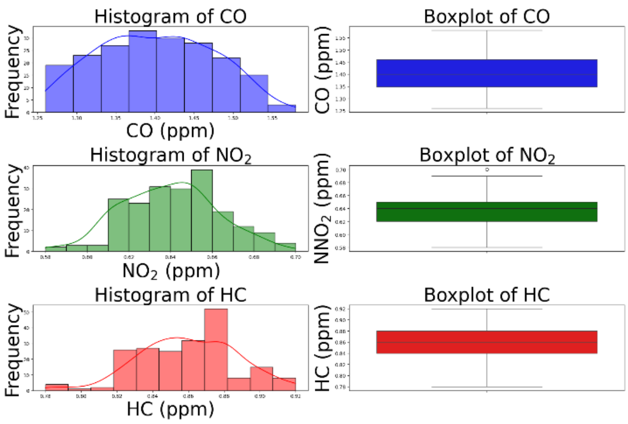

Fig 5. Boxplot of CO, NO_2, and HC

The correlation matrix between the three variable CO, NO_2, and HC is shown in Figure 6. The correlation coefficient in this matrix, which ranges from -1 to 1, is used to indicate the direction and strength of the association between these variables. Perfect positive correlation has a value of 1, perfect negative correlation has a value of -1, and no correlation has a value of 0.

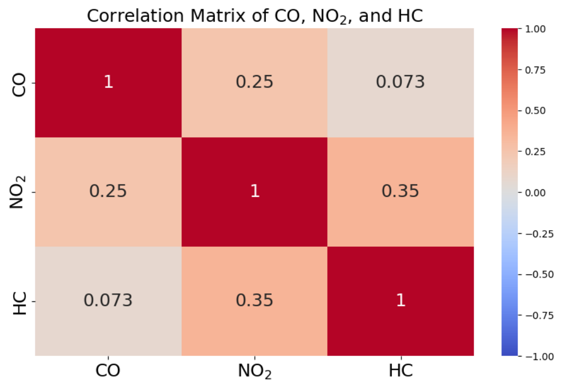

Fig 4. Matrix correlation of CO, NO_2, and HC

The correlation matrix reveals that while CO has almost no correlation with NO_2, CO shows a moderate negative relationship with HC. In contrast, NO_2 and HC have a strong positive correlation, indicating that these two pollutants tend to increase or decrease together. Understanding these relationships is critical for air quality management and pollution control strategies. This relationship is demonstrated where, when oxygen is reduced during combustion, it increases the formation of CO, while NO_2 and HC are reduced. Conversely, when high temperatures during combustion increase the formation of NO_2 and HC, CO is reduced. This proves that NO_2 and HC measurements have a strong positive correlation.

8. CONCLUSIONS

This paper presented an air quality early warning system utilizing IoT devices equipped with catalytic gas sensors to monitor concentrations of CO, NO_2, and HC. The system uses the Classification and Regression Tree (CART) algorithm for data analysis. A web application was developed for real-time data visualization and CSV download, complemented by Telegram notifications for immediate user alerts. During the evaluation, the system demonstrated its effectiveness in detecting and reporting pollutant concentrations in real-time. Subsequent efforts will focus on improving the precision and dependability of the system, broadening the scope of contaminants seen, and using sophisticated machine learning methodologies to improve prognostic capacities. Further development through expanding the system's indoor or outdoor test points can be considered.

9. ACKNOWLEDGEMENTS

Thank you to all parties who have supported this research, especially the Mechanical Laboratory of State Polytechnic of Malang. Your support and cooperation are invaluable in efforts to develop and implement the Early Warning System (EWS) for air quality monitoring. We hope that the results of this research are beneficial and can be applied to enhance environmental safety and health, as well as contribute to sustainable development.

10. AUTHOR CONTRIBUTIONS

Conception and design: Alfiandi Aulia Rahmadani
Methodology: Alfiandi Aulia Rahmadani, Budhy Setiawan and Yan Watequlis Syaifudin
Data acquisition: Alfiandi Aulia Rahmadani and Yan Watequlis Syaifudin
Analysis and interpretation of data: Alfiandi Aulia Rahmadani, Budhy Setiawan and Yan Watequlis Syaifudin
Writing publication: Alfiandi Aulia Rahmadani, Yan Watequlis Syaifudin, Nobuo Funabiki, and Triana Fatmawati
Approval of final publication: Yan Watequlis Syaifudin
Resources, technical and material supports: Budhy Setiawan, Yan Watequlis Syaifudin, and Indrazno Siradjuddin
Supervision: Budhy Setiawan and Yan Watequlis Syaifudin

11. REFERENCES

[1] Menteri Lingkungan Hidup Dan Kehutanan Ri, *Peraturan Menteri Lingkungan Hidup Dan Kehutanan Ri Nomor P14 MENLHK SETJEN KUM1 7 2020*.

[2] Presiden Republik Indonesia, "PP No. 41 Tahun 1999 tentang Pengendalian Pencemaran Udara."

[3] Y. Shen *et al.*, "Dynamic emission characteristics and control strategies of air pollutants from motor vehicles in downtown Beijing, China," *Journal of Environmental Sciences*, vol. 136, pp. 637–646, 2024, doi: https://doi.org/10.1016/j.jes.2023.01.019.

[4] O. M. Sobrinho, L. D. Martins, R. Pedruzzi, W. Vizuete, and T. T. de A. Albuquerque, "From mining to fire outbreaks: The relative impact of pollutants sources on air quality in the metropolitan area of Belo Horizonte," *Atmos Pollut Res*, vol. 15, no. 6, p. 102118, 2024, doi: https://doi.org/10.1016/j.apr.2024.102118.

[5] X. Liu, G. Li, S. Ma, J. Tian, L. Liu, and W. Zhu, "Urban road traffic scale analysis from the perspective of atmospheric

environmental indicators in Tianjin, China," *Ecol Indic*, vol. 82, pp. 392–398, 2017, doi: https://doi.org/10.1016/j.ecolind.2017.07.013.

[6] G. Lou, H. Ma, T. Fan, and H. K. Chan, "Impact of the dual-credit policy on improvements in fuel economy and the production of internal combustion engine vehicles," *Resour Conserv Recycl*, vol. 156, p. 104712, 2020, doi: https://doi.org/10.1016/j.resconrec.2020.104712.

[7] L. Bai *et al.*, "Exposure to ambient air pollution and the incidence of congestive heart failure and acute myocardial infarction: A population-based study of 5.1 million Canadian adults living in Ontario," *Environ Int*, vol. 132, p. 105004, 2019, doi: https://doi.org/10.1016/j.envint.2019.105004.

[8] C. D. Codispoti *et al.*, "Traffic pollution is associated with early childhood aeroallergen sensitization," *Annals of Allergy, Asthma & Immunology*, vol. 114, no. 2, pp. 126-133.e3, 2015, doi: https://doi.org/10.1016/j.anai.2014.10.020.

[9] B. Esty and W. Phipatanakul, "School exposure and asthma," *Annals of Allergy, Asthma & Immunology*, vol. 120, no. 5, pp. 482–487, 2018, doi: https://doi.org/10.1016/j.anai.2018.01.028.

[10] Y. Hassoun, C. James, and D. I. Bernstein, "The Effects of Air Pollution on the Development of Atopic Disease," *Clin Rev Allergy Immunol*, vol. 57, no. 3, pp. 403–414, 2019, doi: 10.1007/s12016-019-08730-3.

[11] A. Dorey, P. Scheerlinck, H. Nguyen, and T. Albertson, "Acute and Chronic Carbon Monoxide Toxicity from Tobacco Smoking," *Mil Med*, vol. 185, no. 1–2, 2020, doi: 10.1093/milmed/usz280.

[12] A. C. Lee *et al.*, "Annealing of Strontium Titanate Based Thermoelectric Materials by Graphite: Mechanistic Analysis by Spectroscopic and Chromatographic Techniques," *Chempluschem*, vol. 85, no. 4, 2020, doi: 10.1002/cplu.202000113.

[13] Z. Xu, Y. Li, Y. Lin, and T. Zhu, "A review of the catalysts used in the reduction of NO by CO for gas purification," 2020. doi: 10.1007/s11356-019-07469-w.

[14] İ. TEMİZER, Ö. CİHAN, and Ö. ÖNCÜOĞLU, "Numerical investigation of different combustion chamber on flow, combustion characteristics and exhaust emissions," *European Mechanical Science*, vol. 7, no. 1, 2023, doi: 10.26701/ems.1181494.

[15] J. Han, L. M. T. Somers, R. Cracknell, A. Joedicke, R. Wardle, and V. R. R. Mohan, "Experimental investigation of ethanol/diesel dual-fuel combustion in a heavy-duty diesel engine," *Fuel*, vol. 275, 2020, doi: 10.1016/j.fuel.2020.117867.

[16] C. K. Yeh, C. Lin, H. C. Shen, N. K. Cheruiyot, D. H. Nguyen, and C. C. Chang, "Real-time energy consumption and air pollution emission during the transpacific crossing of a container ship," *Sci Rep*, vol. 12, no. 1, 2022, doi: 10.1038/s41598-022-19605-7.

[17] N. Salman, A. H. Kemp, A. Khan, and C. J. Noakes, "Real Time Wireless Sensor Network (WSN) based Indoor Air Quality Monitoring System," *IFAC-PapersOnLine*, vol. 52, no. 24, pp. 324–327, 2019, doi: https://doi.org/10.1016/j.ifacol.2019.12.430.

[18] B. W. Dionova, M. N. Mohammed, S. Al-Zubaidi, and E. Yusuf, "Environment indoor air quality assessment using fuzzy inference system," *ICT Express*, vol. 6, no. 3, pp. 185–194, 2020, doi: https://doi.org/10.1016/j.icte.2020.05.007.

[19] E. Sharma, R. C. Deo, R. Prasad, and A. V Parisi, "A hybrid air quality early-warning framework: An hourly forecasting model with online sequential extreme learning machines and empirical mode decomposition algorithms," *Science of the Total Environment*, vol. 709, 2020, doi: 10.1016/j.scitotenv.2019.135934.

[20] Y. J. Son, Z. C. Pope, and J. Pantelic, "Perceived air quality and satisfaction during implementation of an automated indoor air quality monitoring and control system," *Build Environ*, vol. 243, p. 110713, 2023, doi: https://doi.org/10.1016/j.buildenv.2023.110713.

[21] A. L. Chiew and N. A. Buckley, "Carbon monoxide poisoning in the 21st century," *Crit Care*, vol. 18, no. 2, p. 221, 2014, doi: 10.1186/cc13846.

[22] D. J. Rupert, J. A. Poehlman, S. A. Damon, and P. N. Williams, "Risk and protective behaviours for residential carbon monoxide poisoning," *Injury Prevention*, vol. 19, no. 2, p. 119, Apr. 2013, doi: 10.1136/injuryprev-2012-040339.

[23] L. Eichhorn, M. Thudium, and B. Jüttner, "The diagnosis and treatment of carbon monoxide poisoning," *Dtsch Arztebl Int*, vol. 115, no. 51–52, p. 863, 2018.

[24] M. E. Moberg *et al.*, "Global, regional, and national mortality due to unintentional carbon monoxide poisoning, 2000–2021: results from the Global Burden of Disease Study 2021," *Lancet Public Health*, vol. 8, no. 11, pp. e839–e849, 2023, doi: https://doi.org/10.1016/S2468-2667(23)00185-8.

[25] P. C. Y. Ng, B. Long, and A. Koyfman, "Clinical chameleons: an emergency medicine focused review of carbon monoxide poisoning," 2018. doi: 10.1007/s11739-018-1798-x.

[26] J. Garg *et al.*, "Cardiovascular abnormalities in carbon monoxide poisoning," *Am J Ther*, vol. 25, no. 3, 2018, doi: 10.1097/MJT.0000000000000016.

[27] V. K. Yadav *et al.*, "Health and Environmental Risks of Incense Smoke: Mechanistic Insights and Cumulative Evidence," 2022. doi: 10.2147/JIR.S347489.

[28] M. Fazlzadeh, R. Rostami, S. Hazrati, and A. Rastgu, "Concentrations of carbon monoxide in indoor and outdoor air of Ghalyun cafes," *Atmos Pollut Res*, vol. 6, no. 4, pp. 550–555, 2015, doi: https://doi.org/10.5094/APR.2015.061.

[29] T. Goto, T. Itoh, T. Akamatsu, N. Izu, and W. Shin, "CO sensing properties of Au/SnO2–Co3O4 catalysts on a micro thermoelectric gas sensor," *Sens Actuators B Chem*, vol. 223, pp. 774–783, 2016, doi: https://doi.org/10.1016/j.snb.2015.09.146.

[30] A. Paliwal, A. Sharma, M. Tomar, and V. Gupta, "Carbon monoxide (CO) optical gas sensor based on ZnO thin films," *Sens Actuators B Chem*, vol. 250, pp. 679–685, 2017, doi: https://doi.org/10.1016/j.snb.2017.05.064.

[31] K. Ravindra, R. Sokhi, and R. Van Grieken, "Atmospheric polycyclic aromatic hydrocarbons: Source attribution, emission factors and regulation," *Atmos Environ*, vol. 42, no. 13, pp. 2895–2921, 2008, doi: https://doi.org/10.1016/j.atmosenv.2007.12.010.

[32] B. Barhoumi, C. Guigue, S. Touil, B. Johnson-Restrepo, M. R. Driss, and M. Tedetti, "Hydrocarbons in the atmospheric gas phase of a coastal city in Tunisia: Levels, gas–particle partitioning, and health risk assessment," *Science of The Total Environment*, vol. 879, p. 162986, 2023, doi: https://doi.org/10.1016/j.scitotenv.2023.162986.